1980 URANIUM ASSESSMENT REPORT, RESULTS, AND FUTURE NURE PLANS

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October 1980

1980 NURE REPORT

Introduction

The National Uranium Resource Evaluation (NURE) program was started in 1974 to make a comprehensive assessment of the uranium resources of the United States. The program was initiated at a time when there was increasing concern over the available uranium supply to support an expanding nuclear power capacity. Specific NURE milestones have been revised from time to time in response to changing information needs and priorities for nuclear reactor and fuel-cycle planning. "An Assessment Report on Uranium in the United States of America", GJO-111(80), herein referred to as the 1980 NURE Report, was published in October 1980 and is the third major report on uranium resources to be released since NURE began: earlier reports are the NURE Preliminary Report of June 1976 GJO-111(76) and the NURE Interim Report of June 1979 GJO-111(79). In addition to these major NURE reports, the U.S. Department of Energy (DOE) Grand Junction Office also publishes annual reports of updated estimates of domestic uranium reserves and potential resources.

The principal emphasis of DOE's NURE program during 1979 and 1980 was to assess the uranium resources in the 116 National Topographic Map Series (NTMS) quadrangle areas which are believed to have the greatest possibility for the occurrence of additional uranium resources. In addition, resources previously assessed for areas outside these quadrangles have been reviewed, and the assessments have been updated. Of the 621 NTMS quadrangle areas that cover the conterminous 48 states and Alaska, NURE resource assessments have now been completed for 135 quadrangles and in portions of about 45 others.

The purpose of this progress report is to review the results presented in the recently published 1980 NURE Report, and to discuss the future plans for the NURE program.

RESOURCE ASSESSMENT

Introduction

The current estimates of uranium resources were developed from an extensive data base accumulated during the last three decades of Government and industry exploration activities, and were enhanced by NURE program investigations of the past 5 years. This data base permitted the development of a systematic and geologically reliable estimate of uranium resources in the United States.

Much new information that affects the estimation of uranium resources, especially potential resources (Fig. 1), has become available since the publication of the NURE Interim Report in June 1979. The current resource estimates for the United States reflect changes since 1979 made necessary by: (1) the acquisition of new information generated by the NURE program on the geologic favorability of potential host rocks; (2) the utilization of an improved method for the estimation of potential resources; (3) results of private exploration and development; (4) conversion of potential resources, mainly from the probable class to reserves; (5) subtraction of uranium produced in the interim period; and (6) reduction of estimated resources available in lower cost categories because of subsequent increased costs.

Resource Classification and Definitions

In the uranium resource classification system used for NURE estimates, reserves are the firmest class of resources, comprising deposits that have been delineated by drilling or other direct sampling methods. Potential resources are the quantities of uranium believed to be present in deposits that are incompletely defined or undiscovered. Potential resources are divided into probable, possible, and speculative classes based on their spatial or geologic relationships to defined resources.

Probable potential resources are those estimated to occur in known productive uranium areas:

- in extensions of known deposits, or
- in undiscovered deposits within known geologic trends or mineralized areas.

Possible potential resources are those estimated to occur in undiscovered or partly defined deposits in formations or geologic settings productive elsewhere within the same geologic province or subprovince.

Speculative potential resources are those estimated to occur in undiscovered or partly defined deposits:

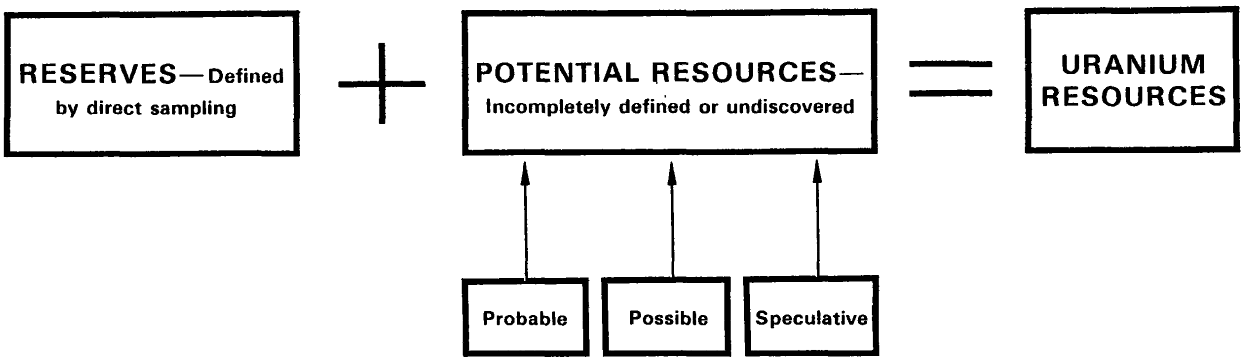
- in formations or geologic settings not previously productive within a productive geologic province or subprovince, or
- within a geologic province or subprovince not previously productive.

Estimated resources are grouped into selected cost (not price) categories of \$30, \$50, and \$100 per pound of U_3O_8 to cover a broad spectrum of economic availability. The applicable costs used to assign the uranium resources to these categories are forward costs comprising operating and capital costs, in 1980 dollars, that would be incurred in producing the uranium. These include costs of power, labor, materials, royalties, payroll and production taxes, insurance, and applicable general and administrative costs. Income taxes, profit, cost of money, and sunk (past) costs are excluded.

In estimating reserves for developed properties, land acquisition and exploratory costs commonly are past expenditures and are therefore excluded from the cost estimates; on the other hand, in estimating potential resources for undeveloped areas, expenditures for these activities usually have not been incurred and are therefore included in the cost estimates. The various cost

FIGURE 1

DOE RESOURCE CLASSES



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categories are independent of the market price at which the uranium would be sold. Unless otherwise specified, resources in each cost category presented in the 1980 NURE Report include the resources in all lower cost categories. Preliminary economic analysis of projected $50 production capability indicates that the price which would support a 15 percent rate of return would be 1.4 to 1.6 times the forward cost per pound of U_3O_8.

Resource Assessment Methodology

All estimates of reserves and potential resources made by DOE and its predecessors before 1979 were single estimates of tons of ore and grade for various cost categories. These estimates were made by experienced uranium geologists and mining engineers according to standardized procedures and represented a reasonable measure of known and postulated resources utilizing the drill-hole and other geologic data available at the time. However, estimates of the total uranium endowment of favorable environments were not made.

Since 1978, new procedures for estimating uranium resources were developed to provide reliability of resource estimates at specific confidence levels, while also making full use of available geologic information and the experience of the estimators in uranium resources. These new procedures were utilized in the 1980 NURE Report, and are standardized and documented to minimize personal biases and to facilitate review and revisions as new resource information is acquired. These current procedures have been designed to optimize the use of the greatly expanded data base provided by the NURE program and the data made available by the private uranium companies.

Reliability of Current Resource Estimates

Since DOE estimates of uranium reserves are based mainly on a large amount of direct measurements and sample data (largely company confidential) for relatively small volumes of mineralized rock, it is not too difficult to obtain a cost effective measure of the accuracy of DOE reserve estimates by comparing ultimate production of the totally "mined-out" deposits with their earlier reserve estimates. Historical comparisons of this type have verified that DOE's reserve estimation procedures and results are sufficiently accurate that they are accepted as the standard by the Federal Government, the domestic mining industry, and other users.

There is no cost effective way, however, to determine directly the accuracy of the current domestic potential resource estimates. As discussed earlier, DOE estimates of potential resources are made by a geologic analogy-subjective probability procedure for large areas for which few, if any, direct sample data for uranium resources are available. Usually only indirect "uranium favorability" types of data are acquirable in a cost effective manner for estimating potential resources of a relatively unknown area. Since these types of indirect geologic data are less precise than the direct measurement types of geologic data available for reserves, a potential resource estimate is inherently less certain than is a reserve estimate.

Even though estimates of uranium potential resources are, by their very nature, less precise than are estimates for uranium reserves, it does not mean that the potential resource estimates are less useful than estimates of reserves. It would probably take hundreds of billions of dollars and many decades of very close-spaced exploration drilling to acquire sufficient direct measurement data to bring DOE's current estimates for potential uranium resources of the United States up to the preciseness or reliability of its current estimates for U.S. uranium reserves.

Through the use of the current NURE resource estimation methodology, it was possible for the first time to define the reliability of potential resources by confidence levels. The confidence levels also provide a computed degree of uncertainty surrounding particular estimates (such as mean values, for example) and should be very useful to Federal planners concerned with probability types of decisions regarding future nuclear fuel cycle program activities. Discussions of how confidence levels provide current potential resource estimates with improved accuracy and also facilitate decision making on probability aspects of nuclear fuel cycle planning will be presented by Mr. David Blanchfield in a subsequent paper of this seminar.

As discussed earlier, DOE's geologic analogy-subjective probability procedure for estimating potential resources is based fundamentally on the acquisition of appropriate amounts and types of "uranium favorability" data to facilitate comparative analysis of new resource areas with "control areas", which is the same general approach used by industry to make resource assessment estimates for oil and gas, and other mineral commodities. Current potential resource estimates were based on an extensive data base generated by private industry exploration and development activities, and by the NURE program activities during the last 5 years. This data base consists primarily of: (1) radiometric logs obtained from hundreds of thousands of industry drill holes; 2) NURE aerial radiometric and magnetic surveys which have covered over 2,400,000 square miles involving about 1,000,000 flight-line miles of data acquisition (Fig. 2); (3) several hundred thousand geochemical samples of stream sediments and surface and ground waters, covering more than 1,800,000 square miles, that have been collected and analyzed (Fig. 3); (4) approximately 380,000 feet of NURE drilling and coring in 18 project areas was accomplished to provide needed subsurface information in specific favorable uranium environments; and, (5) nearly 200,000 feet of spectral radiometric logging was done to further enhance subsurface evaluation. To enhance data correlation and evaluation, surface geologic data for 245 NTMS quadrangles were compiled to supplement the available 1:250,000-scale U.S. Geological Survey geologic maps. Compilation and utilization of the various data bases were accomplished by geologists who spent an average of 4 man years in the field examination of each of the 135 high priority NTMS quadrangles that were totally assessed for the 1980 NURE Report (Fig. 4).

Although the reliability of a uranium resource assessment cannot be simply equated to the size and type of data base acquired for the assessment, most earth scientists would probably agree that the two factors are strongly related. It is believed that the NURE data base for making resource estimates is of sufficient size and quality to lend much geologic credibility to the results.

The current NURE potential resource estimation methodology provides information not available from most other applied uranium resource estimation methodologies, namely geographic delineation and geologic characterization of the estimated resources. The methodology also provides statistical

FIGURE 2

AERIAL RADIOMETRIC SURVEYS COMPLETED

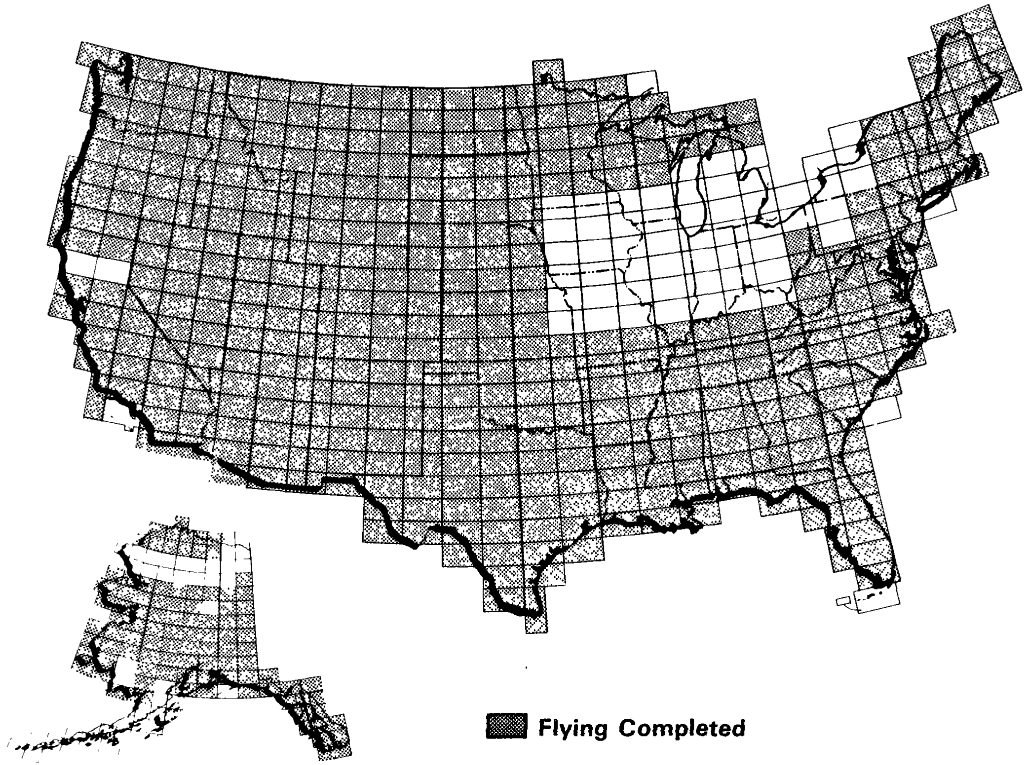

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FIGURE 3

HYDROGEOCHEMICAL AND STREAM SEDIMENT SAMPLING COMPLETED

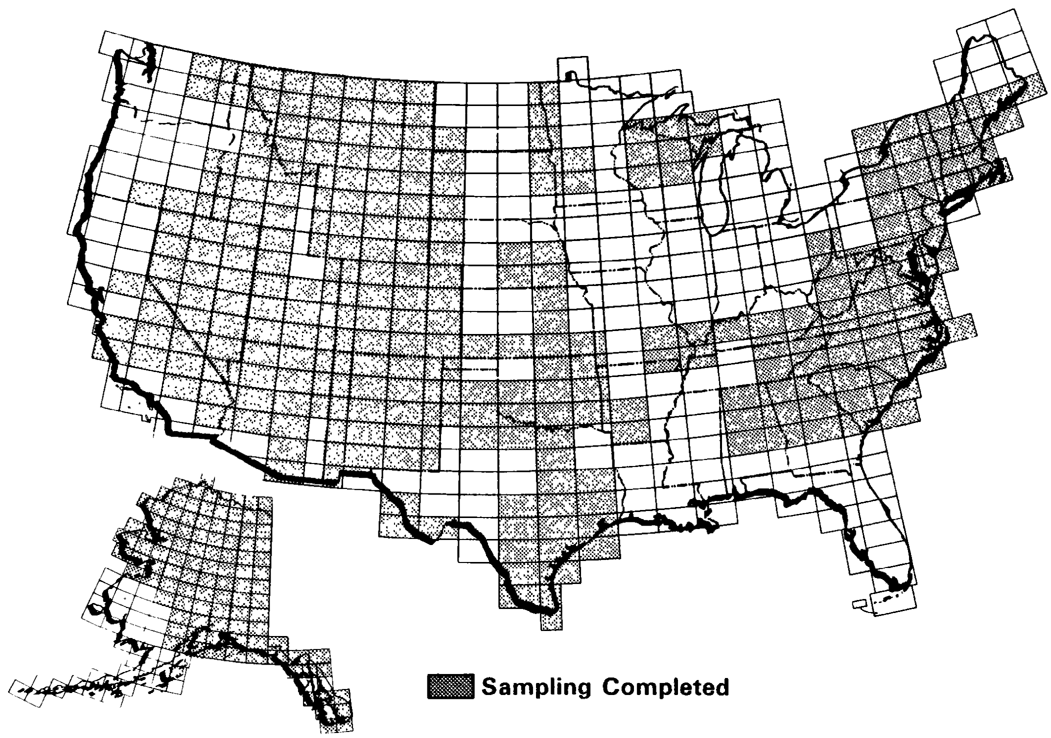

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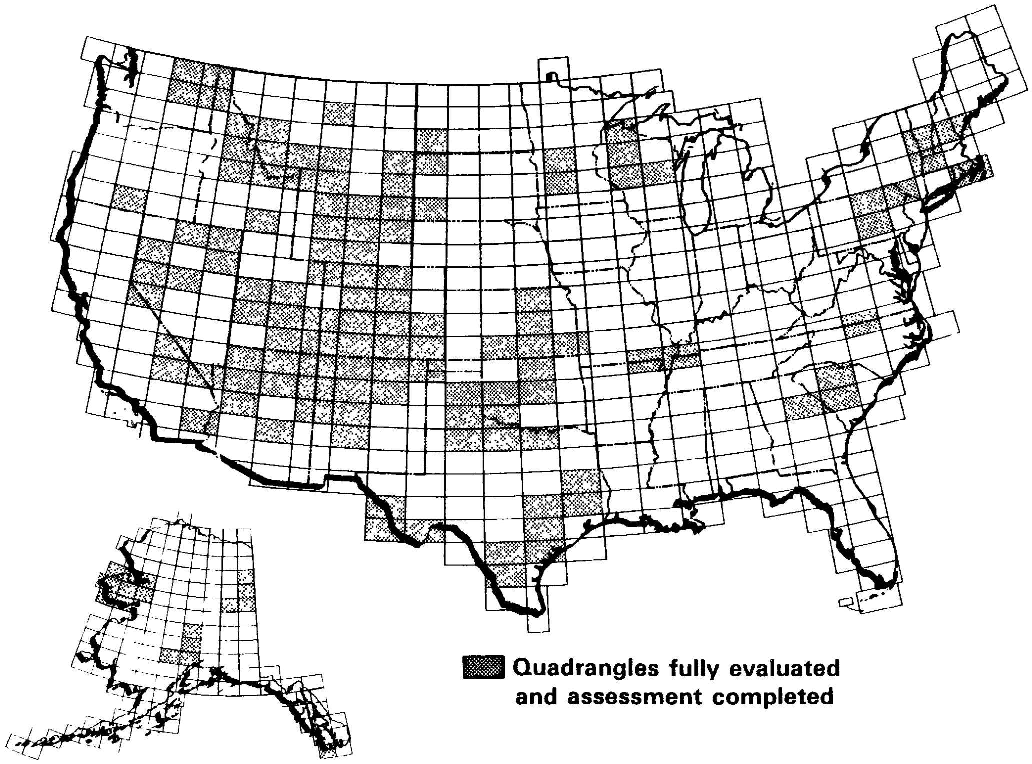
FIGURE 4

NTMS QUADRANGLES FULLY EVALUATED AND ASSESSED FOR 1980 NURE REPORT



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quantification of the reliability of estimates in probability distributions within stated confidence intervals to assist probability-type decision making. These attributes, coupled with utilization of the data base residing at DOE's Grand Junction Office, provide the most comprehensive and geologically reliable estimates of domestic uranium resource available.

Summary of Regional Assessments

To facilitate the analysis and reporting of the resource estimates, the United States was divided into 13 resource regions on the basis of geologic and physiographic characteristics (Fig. 5). To assist in the management and reporting of field work, geologic evaluations were accomplished using areas defined by NTMS 1:250,000-scale quadrangles. Uranium resources were estimated for all favorable areas within the 135 highest priority NTMS quadrangles (Fig. 4), and additionally, favorable areas within portions of other NTMS quadrangles also were assessed to arrive at the total U.S. resource estimates (Plate 1).

Cumulative probability distribution curves, from which the mean expected values for each resource class and appropriate cost category of National resources, were derived (Fig. 6). These probability distribution curves have a distinct advantage over the former "single value estimation procedure" in that they provide a range of expected values at different confidence intervals which should facilitate probability-type decision making for long-range nuclear fuel cycle planning. For example, close study of the cumulative probability distribution curve for the \$50 per pound U_3O_8 probable resource estimate for the United States (Fig. 6, curve 2) reveals the following information: (1) there is a 95 percent probability that the amount of \$50/lb probable resources is greater than 1,102,000 tons U_3O_8 and only a 5 percent chance that it exceeds 1,802,000 tons U_3O_8 for the specific areas assessed; (2) the mean expected value for these probable resources is 1,430,000 tons U_3O_8; and, (3) the amount of \$50/lb probable resources expected to occur within any desired probability interval can be read directly from the probability curves. These types of probability data on uranium resources could be combined with sensitivity analyses (and other systems planning techniques) to assist in the evaluation of future needs for uranium enrichment capacity, number of operating nuclear reactors, amount of nuclear waste fuel that must be planned for long-range storage, and other requirements.

The 1980 NURE Report presents summaries of U.S. resource estimates in several ways, in addition to the cumulative probability distribution curves mentioned earlier to facilitate resource analyses and planning activities. For example, summaries by region of uranium inventory and uranium endowment (Fig. 7), and the distribution by region and forward-cost categories of U.S. uranium reserves and potential resources (Fig. 8) were prepared to elucidate the relative importance of each resource region with respect to their total resource position as of October 1, 1980. Special summaries such as the distribution of \$100/lb U_3O_8 potential resources by geologic age of host rock (Fig. 9) and by type of host rock (Fig. 10) were prepared to facilitate geologic analysis. Similarly, summaries of uranium resources by resource class and cost categories and with three probability distribution values (mean, 95th percentile, and 5th percentile) were prepared (Fig. 11) to

FIGURE 5

RESOURCE ASSESSMENT REGIONS

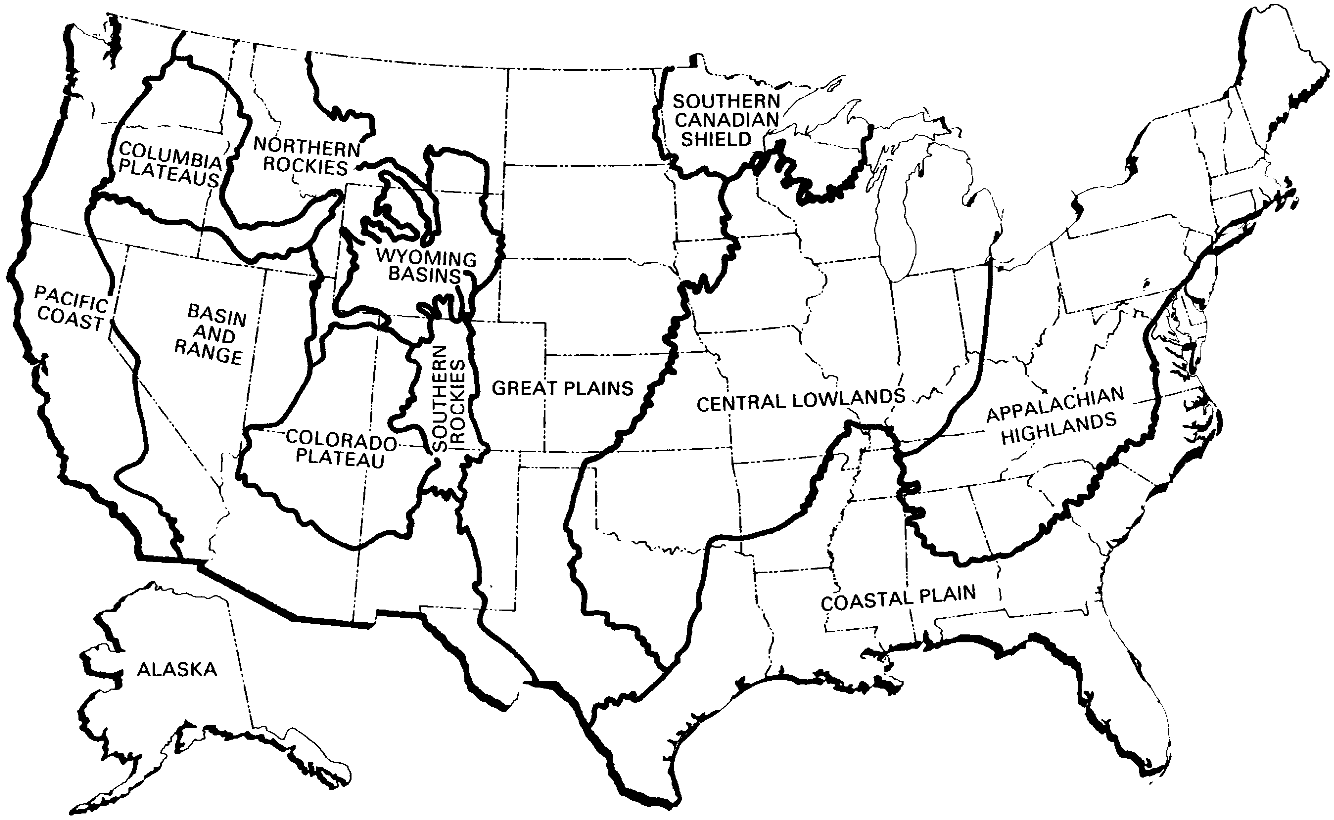

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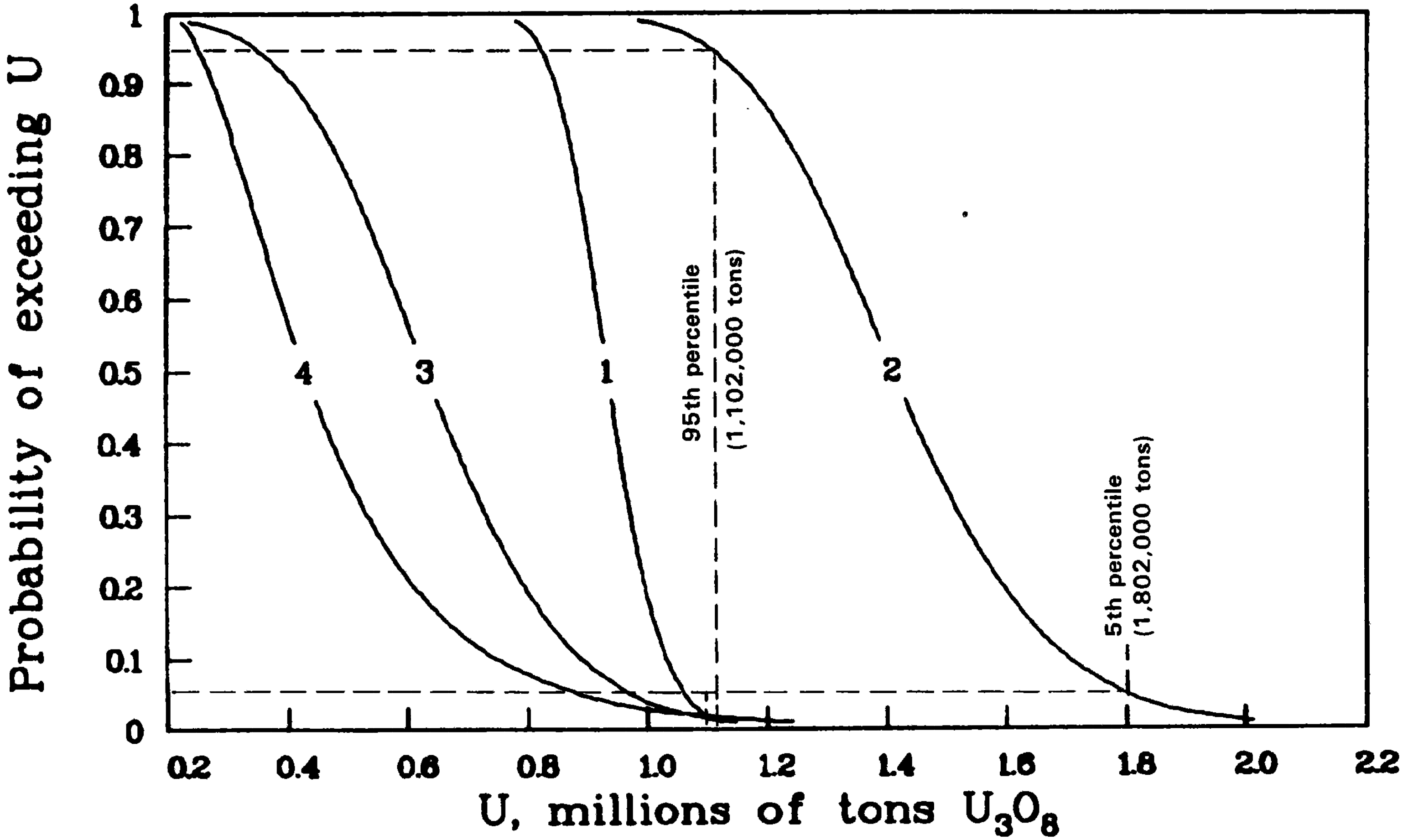
FIGURE 6

CUMULATIVE PROBABILITY DISTRIBUTIONS OF $50/lb RESOURCES OF THE UNITED STATES



1. RESERVES – Mean : 0.94
2. PROBABLE – Mean : 1.43
3. POSSIBLE – Mean : 0.64
4. SPECULATIVE – Mean : 0.48

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FIGURE 7

SUMMARY BY REGION OF URANIUM INVENTORY AND URANIUM ENDOWMENT

Region	Mean tons U_3O_8			
	Uranium inventory[1]	Uranium endowment[2]		
		Probable	Possible	Speculative
Colorado Plateau	801.4	1,119.0	902.2	46.9
Wyoming Basins	556.9	846.2	187.8	38.4
Coastal Plain	86.0	485.3	118.7	20.2
Northern Rockies	30.2	86.8	32.5	367.9
Southern Rockies	37.3	158.2	109.7	70.9
Great Plains	20.7	121.6	112.3	287.5
Basin and Range	66.5	634.0	325.4	108.3
Pacific Coast	3.0	23.7	—	5.2
Central Lowlands	0	—	—	139.8
Appalachian Highlands	0	—	—	168.0
Columbia Plateaus	0	—	—	43.8
Southern Canadian Shield	0	—	—	0.4
Alaska	0	3.0	—	1.4
Totals (rounded)	1,602.0	3,478.0	1,789.0	1,299.0

[1]Uranium inventory includes the estimates of reserves shown in Figure 8 plus additional material above 0.01 percent U_3O_8 that does not meet the economic criteria for reserves.

[2]Uranium endowment includes the estimates of potential resources shown in Figure 8 plus additional material above 0.01 percent U_3O_8 that does not meet the economic criteria for potential resources.

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FIGURE 8

DISTRIBUTION BY REGION & FORWARD-COST CATEGORY U.S. URANIUM RESERVES & POTENTIAL RESOURCES OCTOBER 1, 1980[1]

Mean tons $U_3O_8 \times 10^3$

	Reserves[2]			Potential resources[2] Probable			Possible			Speculative		
Region	$30	$50	$100	$30	$50	$100	$30	$50	$100	$30	$50	$100
Colorado Plateau	355.5	475.6	542.3	329.2	548.9	778.4	159.5	331.2	546.9	4.8	9.7	18.2
Wyoming Basins	180.9	305.8	407.8	116.1	271.4	480.5	45.8	94.0	132.6	3.3	9.2	19.2
Coastal Plain	43.3	54.7	61.0	225.2	277.0	329.4	50.2	61.1	72.8	5.3	7.0	9.5
Northern Rockies	19.2	25.6	26.2	17.4	25.4	41.1	13.7	19.5	24.6	62.0	91.3	125.5
Southern Rockies	25.3	32.3	32.7	89.0	107.3	122.5	37.9	50.1	61.4	34.4	43.6	52.4
Great Plains	10.3	14.1	18.0	22.3	46.5	70.7	18.6	37.7	59.2	60.5	112.8	173.6
Basin and Range	9.1	25.8	31.4	75.0	135.0	244.4	20.4	47.7	107.2	24.0	41.8	64.3
Pacific Coast	1.4	2.1	2.6	8.2	12.0	16.0	—	—	—	2.7	3.7	4.5
Central Lowlands	0	0	0	—	—	—	—	—	—	29.9	47.1	80.0
Appalachian Highlands	0	0	0	—	—	—	—	—	—	79.7	104.7	127.1
Columbia Plateaus	0	0	0	—	—	—	—	—	—	4.5	10.1	20.4
Southern Canadian Shield	0	0	0	—	—	—	—	—	—	0.2	0.3	0.4
Alaska	0	0	0	2.3	2.4	2.5	—	—	—	0.1	0.2	0.4
Totals (rounded)	645.0	936.0	1,122.0	885.0	1,426.0	2,080.0	346.0	641.0	1,005.0	311.0	482.0	696.0

[1]For each line item and resource class, resource totals are cumulative at the $50 and $100 costs.

[2]Mean values are rounded to the nearest 100 tons U_3O_8 for each cost within the resource classes.

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FIGURE 9

DISTRIBUTION OF $100/lb U_3O_8 POTENTIAL RESOURCES BY GEOLOGIC AGE OF HOST ROCK

	Mean tons U_3O_8					
Geologic age	Probable	(%)	Possible	(%)	Speculative	(%)
Quaternary	9,000	(<1)	0	(0)	2,000	(<1)
Tertiary	1,085,000	(52)	359,000	(36)	203,000	(29)
Cretaceous	74,000	(4)	66,000	(7)	70,000	(10)
Jurassic	640,000	(31)	416,000	(41)	3,000	(<1)
Triassic	118,000	(6)	58,000	(6)	66,000	(10)
Paleozoic	31,000	(1)	84,000	(8)	251,000	(36)
Precambrian	123,000	(6)	22,000	(2)	101,000	(14)
Totals	2,080,000	(100)	1,005,000	(100)	696,000	(100)

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FIGURE 10

DISTRIBUTION OF \$100/lb U_3O_8 POTENTIAL RESOURCES TYPE OF HOST ROCK

Host rock	Mean tons U_3O_8					
	Probable	(%)	Possible	(%)	Speculative	(%)
Sandstone	1,820,000	(87)	898,000	(89)	469,000	(67)
Conglomerate	57,000	(3)	16,000	(2)	25,000	(4)
Granitic and metamorphic rocks	106,000	(5)	26,000	(3)	159,000	(23)
Volcanic rocks	56,000	(3)	35,000	(4)	25,000	(4)
Limestone	21,000	(1)	22,000	(2)	14,000	(2)
Lignite	20,000	(1)	8,000	(<1)	4,000	(<1)
Totals	2,080,000	(100)	1,005,000	(100)	696,000	(100)

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FIGURE 11

URANIUM RESOURCES OF THE UNITED STATES[1]

Forward-cost category	Tons U_3O_8		
	Probability distribution values		
	Mean	95th percentile[2]	5th percentile[2]
$30/lb U_3O_8			
Reserves	645,000	567,000	729,000
Probable	885,000	659,000	1,161,000
Possible	346,000	194,000	530,000
Speculative	311,000	155,000	600,000
Totals	2,187,000	1,731,000	2,748,000
$50/lb U_3O_8			
Reserves	936,000	821,000	1,060,000
Probable	1,426,000	1,102,000	1,802,000
Possible	641,000	346,000	973,000
Speculative	482,000	251,000	890,000
Totals	3,485,000	2,771,000	4,313,000
$100/lb U_3O_8			
Reserves	1,122,000	971,000	1,291,000
Probable	2,080,000	1,646,000	2,573,000
Possible	1,005,000	521,000	1,526,000
Speculative	696,000	378,000	1,225,000
Totals	4,903,000	3,875,000	6,056,000

[1]Uranium resources are estimated in-place quantities. Losses due to processing may range from 5 to 15 percent.

[2]The 95th percentile indicates a 95-percent confidence in the existence of at least the amounts shown. The 5th percentile indicates a 5-percent chance of the existence of more than the amounts shown. The values for resources at the 95th and 5th percentiles are not directly additive, as explained in the Methodology section of the 1980 NURE Report.

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facilitate the evaluation of the domestic uranium resource position relative to uranium supply-demand forecasts.

An analysis of the estimated uranium resources of the United States (Fig. 12) indicates a range of reserves, in mean values, from 645,000 tons U_3O_8 at \$30 per pound U_3O_8 to 1,122,000 tons U_3O_8 at \$100 per pound of U_3O_8. Ranges for potential resources for the same cost categories are: from 885,000 to over 2,000,000 tons U_3O_8 in the probable resource class; from 346,000 to over 1,000,000 tons U_3O_8 in the possible resource class; and from 311,000 to nearly 700,000 tons U_3O_8 in the speculative resource class. In addition to the above estimated resources, there are an estimated 140,000 tons U_3O_8 that could be recovered as a byproduct of phosphate and copper mining through the year 2009.

Further study reveals that 80 percent of the estimated \$50 per pound U_3O_8 potential resources occur in only 20 percent of the favorable areas assessed (Fig. 13), and these \$50 resources declined in all resource classes from a combined total of about 3,200,000 tons U_3O_8 in 1979 to about 2,600,000 tons U_3O_8 as of October 1980. This reduction resulted primarily from the combined impacts of more detailed analyses, revealing less favorable geologic conditions in several areas than previously surmised; and, probably more importantly, rising costs which caused some of these resources to become unavailable at costs of \$50 per pound. The \$100 cost category, which is now estimated to be about 3,700,000 tons U_3O_8, includes most of the resources that were removed from the \$50 forward-cost category due to cost increases.

Studies of the ages and lithologic characteristics of the host rocks for the currently estimated potential resources reveal that 84 percent of all potential resources are in sandstone (Fig. 10), 44 percent are in host rocks of Tertiary age and 28 percent are in host rocks of Jurassic age (Fig. 9). These distributions have changed little over the last few years.

Special Assessment Studies

In addition to the relatively high grade, "conventional" uranium resources just discussed, the NURE program is also investigating other types of uranium resources, including "intermediate-grade" deposits; "world-class" deposits; Chattanooga Shale; seawater; phosphate, copper, aluminum, and beryllium byproduct; enrichment plant tails; and mill tailings (Fig. 14). The purpose of these special studies is to determine the total amounts of uranium estimated to be contained in these sources, or, where data are sufficient, to estimate the amounts that would be available in the standard forward-cost concept. Although a few of these special studies will be continuing for several years, progress to date for each study is summarized in the 1980 NURE Report.

Intermediate Grade Deposits -- An Intermediate-Grade program was started in 1979 to evaluate the possible existence of large resources of uranium in the range of 0.01 to 0.05 percent U_3O_8. Initially, three sites were selected: Great Divide Basin, Wyoming; Sand Wash Basin, Colorado; and Copper Mountain, Wyoming (Fig. 15), for which the investigations and resource assessments have been completed (Fig. 16). The results of the studies of these sites will be used in coming years as analog models or control areas for evaluation of the much larger environment associated with each site.

FIGURE 12

UNITED STATES URANIUM RESOURCES OCTOBER 1, 1980

$/lb U_3O_8 Cost Category	Tons U_3O_8			
	Reserves	Potential Resources		
		Probable	Possible	Speculative
$30	645,000	885,000	346,000	311,000
$30-$50 increment	291,000	541,000	295,000	171,000
$50	936,000	1,426,000	641,000	482,000
$50-$100 increment	186,000	654,000	364,000	214,000
$100	1,122,000	2,080,000	1,005,000	696,000

NOTE: Uranium that could be recovered as a byproduct of phosphate and copper mining through the year 2000 is estimated at 120,000 tons U_3O_8.

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FIGURE 13

DISTRIBUTION OF $50 POTENTIAL RESOURCES IN ASSESSED AREAS OCTOBER 1980

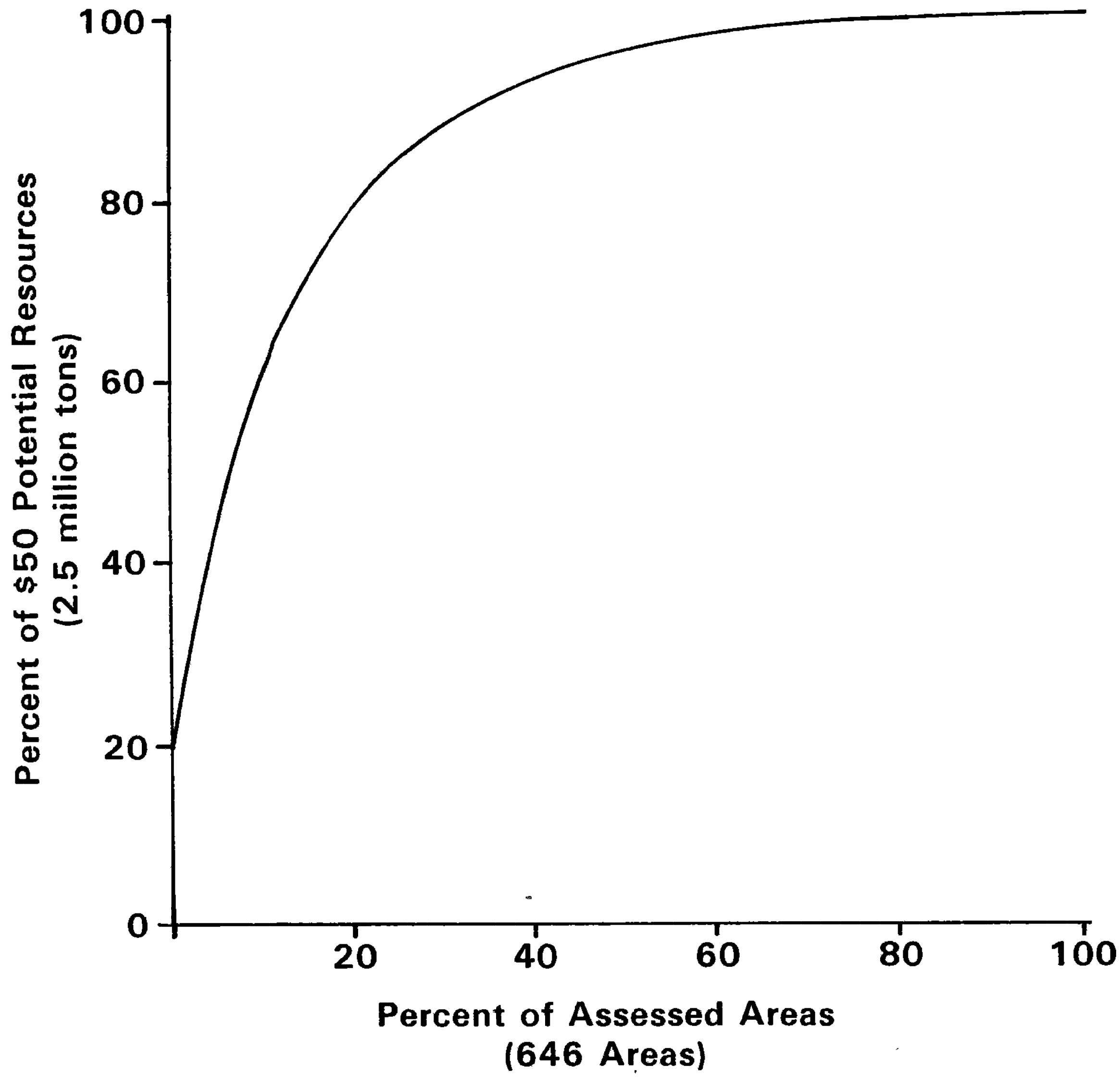

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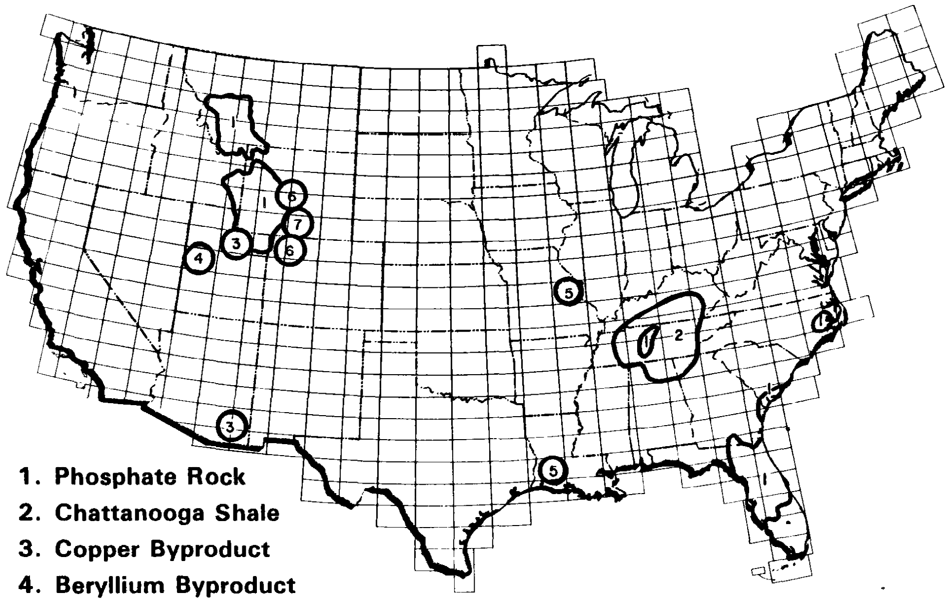
FIGURE 14

AREAS OF URANIUM SOURCES INCLUDED IN SPECIAL STUDIES



1. Phosphate Rock
2. Chattanooga Shale
3. Copper Byproduct
4. Beryllium Byproduct
5. Red Mud
6. Intermediate Grade
7. World Class

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FIGURE 15

NURE SITES SELECTED FOR INTERMEDIATE-GRADE RESOURCE ASSESSMENT STUDIES

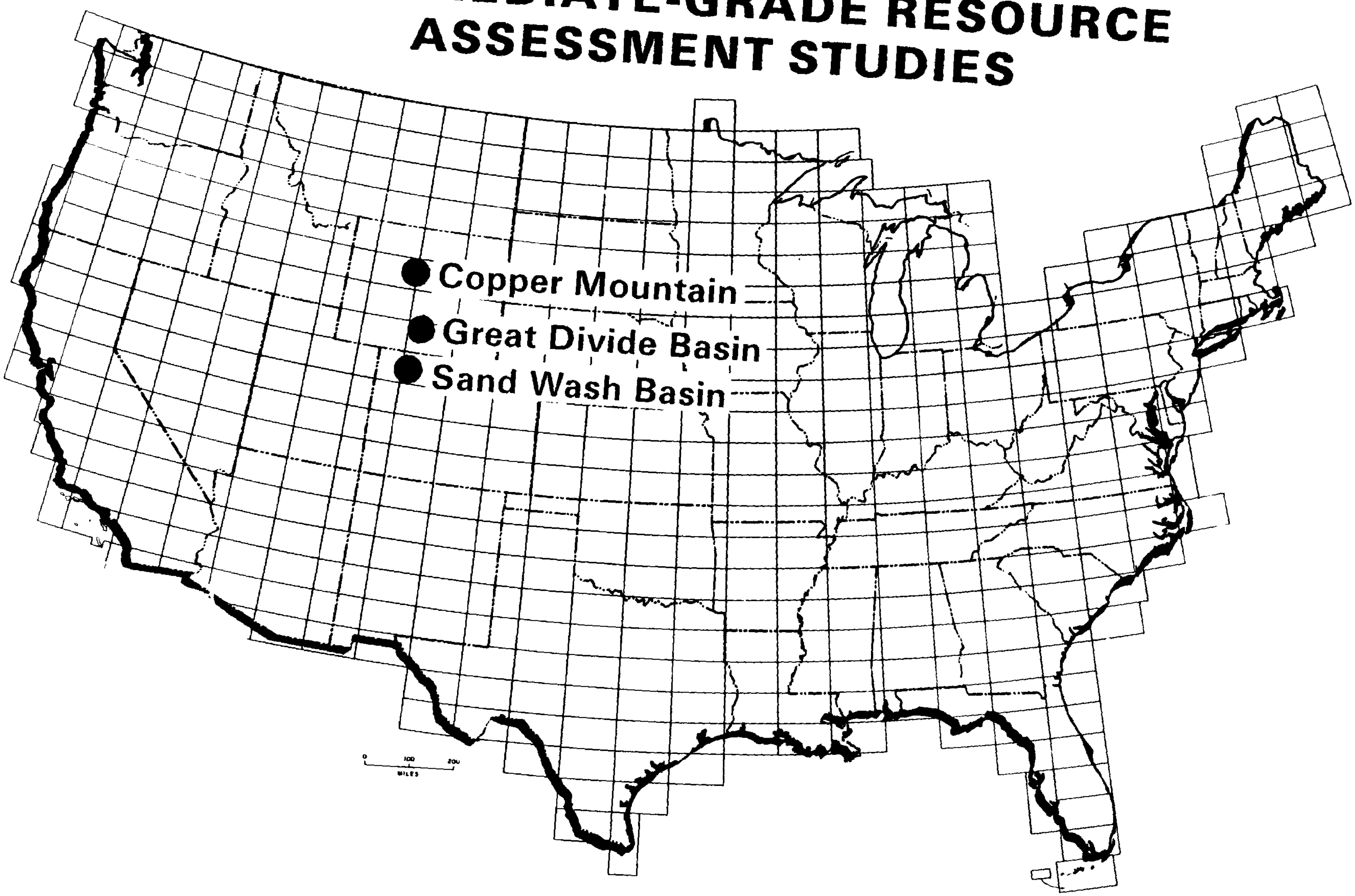

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FIGURE 16

ESTIMATED INTERMEDIATE-GRADE RESOURCES

Site location	Site area sq mi	Mean tons U_3O_8 $30/lb[1]	$50/lb[1]	$100/lb[1]	Endowment
Great Divide Basin	4.5	—	—	23	17,754
Sand Wash Basin	4.0	14	367	2,417	9,101
Copper Mountain	1.0	484	4,704	15,810	20,050
Totals		498	5,071	18,250	46,905

[1]Forward-cost category

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World-Class Deposits

The study of World-Class deposits of uranium was begun in 1978 to provide a geologic evaluation of types of deposits that are important sources of uranium production elsewhere in the world but as yet are unknown within the United States. Precambrian quartz-pebble conglomerate was selected as the first geologic environment to be evaluated. This type of deposit is an economic source of uranium in the Witwatersrand, South Africa, and the Elliot Lake area, Ontario, Canada.

The Canadian conglomerates are highly pyritic and have been dated at about 2,500 million years. They unconformably overlie an Archean basement of granite, greenstone, and minor mafic intrusive rocks, and they contain primary uranium minerals that are most likely of detrital origin.

Two U.S. sites were first examined. One was located in the Black Hills of South Dakota and the other in the Sierra Madre and Medicine Bow Mountains areas of southeastern Wyoming (Fig. 17). Drilling, which started in 1979, led to the selection of the Wyoming site for detailed investigations. In the Sierra Madre and the Medicine Bow Mountains, the upper part of the Phantom Lake Suite and the lower Magnolia Formation of the Deep Lake Group are comparable in age and lithology to the Canadian quartz-pebble conglomerates. Surface samples from the Sierra Madre and Medicine Bow Mountains contain as much as 130 to 150 ppm U_3O_8. Preliminary analyses of cores from over 13,000 feet of drilling in these areas indicate that some core contained concentrations ranging up to 1,400 ppm U_3O_8.

The estimated resources of the Precambrian conglomerate site studied in Wyoming are shown in Figure 18.

Chattanooga Shale -- The Chattanooga Shale of Devonian and Mississippian age extends, with fairly uniform thickness and lithology, over hundreds of square miles of the east-central United States. It is a massive, siliceous, pyritic marine black shale. The Chattanooga Shale consists of the Dowelltown Member and the overlying Gassaway Member. Each member is about 15 feet thick, and the Gassaway contains from 55 to 70 ppm U.

The Gassaway Member, in DeKalb County, Tennessee, is estimated to contain about 5 million tons of U_3O_8. A 1978 study by Mountain States Research and Development, sponsored by DOE, showed that byproducts from uranium recover could include oil, ammonia, sulfur, vanadium, cobalt, nickel, and molybdenum. Exploitation would require underground mining and the processing of large tonnages at high efficiency and low cost. If the shale contained an average of 65 ppm U, a plant treating 100,000 tons of shale daily could conceivably produce annually: 2,360 tons of U_3O_8, 10,650 tons of vanadium, 19.3 million barrels of oil, 171,500 tons of ammonia, and 790,000 tons of sulfur.

Phosphate processing -- The two major areas of phosphate resources in the United States occur in the southeast and in the west (Fig. 14). Under a DOE contract, these resources were studied by Earth Sciences, Inc. in 1979 to determine: (1) the technical, economic, and environmental feasibility of uranium recovery, and (2) the quantities of uranium that might be recovered through the year 2025 as a single product, a byproduct, or a coproduct. The

FIGURE 17

WORLD-CLASS RESOURCE STUDIES CONGLOMERATE IN WYOMING SUB-PROVINCE

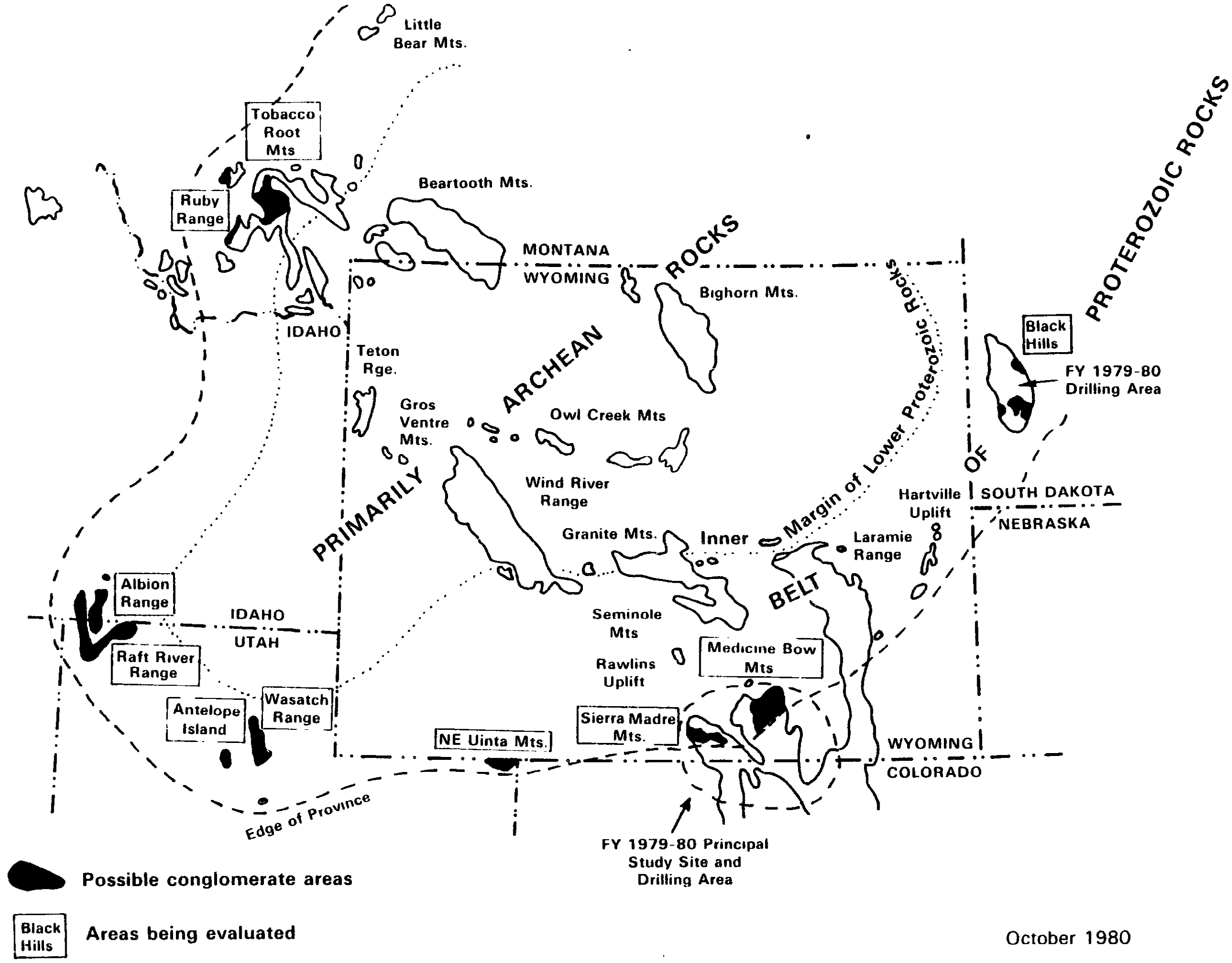

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FIGURE 18

ESTIMATED WORLD-CLASS RESOURCES

Site location	Site area sq mi	Mean tons U_3O_8 $30/lb[1]	$50/lb[1]	$100/lb[1]	Endowment
Black Hills	10.0	—	—	—	—
Sierra Madre-Medicine Bow Mtns.	13.5	60	480	1,390	3,150

[1]Forward-cost category

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conclusion from the study was that uranium availability from phosphate resources during the next 50 years will be almost entirely dependent upon the production of wet-process phosphoric acid. No other phosphate product is considered to be a viable source of uranium during the next several decades, because no other process has been found that will selectively extract uranium.

In 1979, it was estimated that the annual production of byproduct uranium by 1980, increasing to 6,000 tons by 1985, and could be 4,4000 tons U_3O_8 then decreasing gradually to about 5,000 tons in 2000 and 4,600 tons in 2025. The total resource is estimated to be about 4 million tons U_3O_8 in the marine phosphorites from which the acid is produced.

Industry is moving into this form of uranium production, with five byproduct plants in operation in 1980 and several more in various stages of design, construction, or startup.

Seawater -- Seawater is a huge, very low-grade source of uranium, averaging 3 to 4 parts per billion but containing perhaps 5 billion tons U_3O_8. A DOE-sponsored conceptual study was conducted by Exxon in 1979 to evaluate the feasibility of recovering uranium from seawater. The parameters studied included: concentration, current flow, temperature, turbidity, and other variables that could affect availability, recoverability, and deliverability of uranium to the extraction plant. Delivery schemes utilizing ocean-current flow, tidal flow, and pumped flow were considered, and the pumped-flow system was chosen for evaluation. Uranium would be recovered by adsorption on hydrous titanium oxide followed by elution with ammonium carbonate solution.

The results show that the recovery of uranium from seawater would be technologically possible but not economically feasible under the conditions and assumptions of the study. Using the most optimistic assumptions regarding technology and economics, the cost of recovery was estimated to be $1,400 per pound U_3O_8. A more recent investigation by the Massachusetts Institute of Technology shows, however, that design optimization and the use of a newly tested adsorber might reduce the cost to about $300 per pound U_3O_8, with the prospect of further reductions.

Copper byproduct -- Uranium is present in most solutions produced by acid leaching of copper waste dumps. Although the concentration of uranium is only 2 to 15 ppm a significant quantity could be recovered by treating major process streams from the larger copper mines in the western United States. Plants in Utah and Arizona now produce U_3O_8 by treating copper-leaching solutions, and the construction of similar facilities at other copper mines and plants could increase the uranium recovery capacity to about 500 to 1,000 tons U_3O_8 annually by the mid-1980s.

Beryllium byproduct -- Beryllium-bearing tuffs in west-central Utah contain 150 to 200 ppm uranium. This apparently unique uranium deposit is being exploited primarily for its beryllium content, but a circuit to recover uranium has been installed and is expected to produce about 17 tons U_3O_8 per year.

Aluminum byproduct -- After alumina has been removed from bauxite by caustic leaching, a solid waste remains called "red mud". Red mud is accumulating at a rate of about 10 million tons annually at plants located in the Mississippi

Valley and along the Gulf Coast. The residues contain some uranium, but the U_3O_8 byproduct potential from red mud probably could not exceed a few hundred tons annually.

Enrichment Plant Tails -- In the natural form, any given quantity of the uranium element (U) actually consists of a mix of several uranium isotopes. About 0.7 percent of the total is the fissionable isotope ^{235}U, and the remainder consists of the radioactive, but nonfissionable, isotope ^{238}U, along with very minute quantities of other isotopes. The ^{235}U portion must be enriched to 2 to 5 percent before it can be used for power plant fuel. During this enrichment, the ^{235}U content of the portion being depleted drops to a certain level (called the tails assay level), and that depleted portion is removed from the circuit. The withdrawn portions (called the tails) still contain some amount of ^{235}U; the actual percentage varies and is determined by the enrichment plant operating procedures at the time of withdrawal.

As a result of past enrichment operations, there were about 285,000 short tons of uranium (U) contained in government-owned stockpiles of enrichment tails as of January 1, 1980.

The tails could be supplied again as feed to the enrichment process to obtain additional ^{235}U product; however, this second effort on already treated feed will not result in the efficiencies of the first pass.

Figure 19 shows a breakdown of the tails stockpile with respect to ^{235}U grades of the material, the quantity of uranium (U) in the material, and the amount of U_3O_8 as equivalent material which could be generated if the tails were enriched to 0.7 percent ^{235}U.

The tails, therefore, represent a potential source of supply to aid in meeting future uranium requirements for nuclear power needs. When and how they would be so utilized would depend on the scarcity of natural uranium from conventional sources and the cost of the additional enrichment involved.

From current DOE enrichment planning, it is estimated that from 1980 through 2009 about 716,600 short tons of uranium (U) will be residual in tails material, assuming a 0.20-percent ^{235}U operating tails assay level. If this material is further enriched at a 0.10-percent tails assay level, an equivalent of 138,600 short tons U_3O_8 (natural) could be obtained.

Mill Tailings -- Reserves contained in uranium mill tailings have been summarized in three categories; inactive tailings, active tailings, and estimated accumulations. Inactive tailings are those materials in storage at discontinued uranium processing operations as of January 1, 1980, while active tailings are those in storage at operating mills as of January 1, 1980. Estimated accumulations are those tailings that would result from conventional mining and milling operations for 1980 through 2009. A summary of these reserves is shown in Figure 20.

The estimated accumulations category contains tailings expected to be created from 1980 through 2009 at the 22 tailings sites active as of January 1, 1980, and at an expected additional 10 to 15 sites.

FIGURE 19

EQUIVALENT U_3O_8 AVAILABLE FROM ENRICHMENT PLANT TAILS

Grade of tails in stockpile	Uranium (U) in tails	Equivalent U_3O_8 (short tons) enriched at tails assay of:	
% ^{235}U	metric tons	0.20% ^{235}U	0.10% ^{235}U
0.30	35,600	9,060	15,150
0.25	77,400	9,840	24,700
0.20	145,100	—	30,860
Totals	258,100	18,900	70,710

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FIGURE 20

RESOURCES CONTAINED IN URANIUM MILL TAILINGS

	$30/lb			$50/lb			$100/lb		
Category	Tons of tailings	% U_3O_8	Recoverable tons U_3O_8	Tons of tailings	% U_3O_8	Recoverable tons U_3O_8	Tons of tailings	% U_3O_8	Recoverable tons U_3O_8
Inactive tailings January 1, 1980	5,433,000	0.037	1,200	9,309,000	0.034	1,600	24,819,000	0.022	2,300
Active tailings January 1, 1980	22,948,000	0.024	2,400	69,618,000	0.018	5,000	146,065,000	0.013	7,200
Estimated accumulations 1980-2009	—	—	—	—	—	—	746,776,000	0.009	23,200

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Supply and Demand Assessment

The magnitude of National demand for uranium to support future nuclear power expansion is, of course, the driving force behind all nuclear fuel cycle activities of the Federal Government and the domestic nuclear industry. The projected rate of nuclear power expansion has been decreasing in recent years, but the latest DOE studies still project considerable growth.

An important dimension to the analysis of uranium development and production is the uranium industry's perception of anticipated demand, market prices, and foreign competition. The uranium-producing industry is currently reacting to the effects of the sharp turndown in price, inventory build-up, the lowering of high-grade uranium deposits. Some plans for expanded or new facilities are being delayed or cancelled; production rates are being reduced; and exploration activities are being sharply curtailed.

The subject of production capability from identified resources based on several scenarios is a significant part of the 1980 NURE Report. Mr. Paul deVergie, in a subsequent seminar paper, will provide a detailed overview of the status of analyses of domestic uranium production capability.

FUTURE NURE PLANS

Reduced nuclear fuel demand projections and the completion in FY 1980 of the assessment of the high priority quadrangles covering all areas containing reserves and probable potential resources, which have the highest certainty of reaching production in the near term, have lessened the urgency for early completion of a comprehensive study of U.S. uranium resources. Consequently, in recent months DOE's Uranium Resource Assessment program has undergone a major strategy modification.

The former comprehensive assessment approach required development of a systematic, nationwide data base. The reoriented program will continue toward previously defined goals but will fulfill objectives through a geologically selective approach of limited site-specific studies in areas identified as favorable for world class, intermediate grade, and conventional uranium resources. This proposed strategy shift requires revisions to NURE activities and the continuation of other uranium resource assessment tasks, as listed below.

- Phase out quadrangle assessment by the end of FY 1981
- Phase in evaluation and assessment of conventional uranium environments by the end of FY 1981
- Continue to evaluate and assess world class and intermediate grade uranium resources
- Terminate the National aerial radiometric and magnetic survey by the end of FY 1981
- Terminate the National hydrogeochemical and stream sediment reconnaissance (HSSR) survey by the end of FY 1981

- Conduct selected supporting activities such as specialized geophysical studies, detailed geochemical studies, and drilling and logging as appropriate and as required for specific sites being investigated

- Continue reserve estimation and supply analysis

- Continue technology applications at reduced levels

- Continue international activities

Potential Resource Assessment

Quadrangle Assessment Phase Out -- The principal Uranium Resource Assessment program activities of the past 2 years have concentrated on the intensive study, evaluation, and assessment of the 116 highest priority quadrangles in the continental United States. An additional 19 quadrangles also were assessed during the past 3 years. The results of these 135 quadrangle assessments and a review of current domestic uranium resources were presented in the 1980 NURE Report. Evaluation of 27 priority quadrangles selected from a preferred group of 73 quadrangles was initiated in FY 1980 and will be completed in FY 1981. This will mark the end of the quadrangle assessment program. The results will be presented with World-Class and Intermediate-Grade resource assessments in the next major uranium assessment report to be published in 1983.

Conventional Resource Assessment Phase In -- FY 1981 will be a transition year in which the quadrangle assessment program will be phased out and specific geologic areas will be selected based on previously collected NURE data for initiation of the Conventional Resource Assessment program in FY 1982.

Conventional resources are defined as those that are found in environments similar to those having known uranium deposits in the United States. The major difference between the two approaches is that the conventional resource area studies will relate to specific favorable geologic units or settings, not constrained by quadrangle or other nongeologic boundaries. These projects will range in area from a few tens of square miles to several thousand square miles. The average project will require 1-1/2 years to complete the evaluation and assessment, but there will be a wide range in the time and effort required for individual projects. Many areas of speculative potential resources and unassessed favorable areas were identified in the quadrangle assessment program. Candidate areas will be prioritized in terms of those most likely to significantly add to the resource base in a short time frame. Under the proposed FY 1982 budget no more than four studies will be initiated for inclusion in the 1983 report.

World-Class Resource Assessment -- The World-Class program is designed to investigate geologic settings in the United States that have characteristics similar to those of some of the more important uranium deposits being exploited elsewhere in the world. The program seeks to identify and assess areas favorable for the occurrence of large, moderate- to high-grade deposits. The program is considered to be a high risk effort, but with possibilities for identifying large resources in the medium- to long-range time frame.

The strategy for the World-Class program is to study and characterize the geologic settings of foreign deposits; identify similar areas in the United States; evaluate the identified areas sufficiently to select those warranting in-depth study; and investigate selected sites in detail. Investigations will be extended as appropriate to assess the potential of the geologic setting. Preliminary geologic studies have been initiated at 13 locations in preparation for intensive investigations. Site investigations will be conducted in a systematic manner, with sufficient geologic study to identify further investigative needs. Two World-Class quartz-pebble conglomerate sites have been studied in 1979 and 1980, and their assessments were included in the 1980 NURE Report. Five additional site studies will be undertaken through FY 1983, each requiring approximately 1-1/2 years to complete. The assessment of three World-Class sites will be included in the 1983 NURE report.

Intermediate-Grade Resource Assessment -- The Intermediate-Grade resource program was conceived to demonstrate the presence of large quantities of uranium resources in the 0.01 percent to 0.05 percent U_3O_8 grade range. As such it will provide the nuclear fuel cycle planners with a higher cost resource base that could be considered as a viable alternative to such high-cost resources as the Chattanooga Shale. The program is regarded as a relatively low-risk effort with prospects of identifying areas with moderate to large resources in a short- to medium-range time frame.

The strategy for the Intermediate-Grade resource program is to select sites within favorable geologic settings based on available industry and NURE reconnaissance data; evaluate and assess the sites and use the findings to model and assess the potential of the larger regional geologic settings in successive years. Three Intermediate-Grade sites have been studied in 1979 and 1980, and their assessments were included in the 1980 uranium assessment report. The resources estimated for these three sites were not large due to the limited size of the sites selected, but the studies served a firm bases for the subsequent evaluations of the larger geologic settings for which substantial potential resources might be assigned. One additional site study will be undertaken each year and will require about 1-year to complete. All completed assessments of two Intermediate-Grade area studies will be included in the 1983 NURE report.

TERMINATION OF NATIONAL DATA GATHERING EFFORT AND INITIATION OF SELECTED SUPPORTING ACTIVITIES

Aerial Surveys -- Upon conclusion of FY 1980 contracted flying, the National Airborne Radiometric and Magnetic Survey will be terminated. Existing data will be processed and open filed by mid-1981. These data will be used in site selection and in evaluating of the need for specialized surveys and/or drilling to support World-Class, Intermediate-Grade, and Conventional Resource investigations.

Hydrogeochemical Surveys -- Upon completion of FY 1980 contracted sampling, the National Hydrogeochemical and Stream Sediment Reconnaissance Survey will be terminated. At that time a backlog of over 200,000 samples will remain, and these samples will be analyzed and reported by the end of FY 1981. The Oak Ridge Gaseous Diffusion Plant will be tasked to archive HSSR samples and, as funding allows, to conduct specialized geochemical surveys, as needed, in support of the reoriented NURE program.

Drilling -- Drilling in support of quadrangle assessment was terminated in FY 1980, but will continue as needed in support of World-Class and Intermediate-Grade investigations. In FY 1982, drilling may be conducted as needed, and as funding permits, for Conventional Resource studies. As in the past, the drilling will generally be wide-spaced (a mile or more between holes), except in the case of Intermediate-Grade site studies, where somewhat closer-spaced holes may be needed to establish continuity of mineralized zones.

Logging -- A NURE logging program activity was initiated in FY 1979 to obtain subsurface uranium resource information from holes drilled for purposes other than uranium exploration, such as oil and gas and ground water. This activity will continue to provide information critical to the long-range resource assessment goal of the Uranium Resource Assessment program, at a fraction of the cost that would be necessary if the program had to finance drilling similar holes to obtain needed subsurface information.

Reserve Estimation and Supply Analysis

Before the inception of NURE, and continuing to the present time, DOE's Grand Junction Office has conducted a program of estimation of ore reserves and potential uranium resources utilizing data voluntarily contributed by the uranium industry. The success of the NURE program in stimulating, expanding, and dispersing some of industry's uranium exploration activities to areas of the United States outside the traditional uranium districts has resulted in data now being available from industry that support the estimation of all three classes of potential uranium resources - probable, possible, and speculative (as well as reserves). DOE's Uranium Resource Assessment program will continue to stress the collection of available industry data with which to estimate and maintain currency of reserves and potential resources. Due to the proprietary nature of the industry data, collection of data and the estimation of reserves and potential resources utilizing these data will continue to be an in-house effort by DOE engineers and geologists. This effort will be closely coordinated with the Conventional Resources program.

Reserves and potential resources, industry production plans and trends will be analyzed to develop supply projections under various uranium cost/price scenarios. Long term uranium production capability will be analyzed in relation to production costs, prices, and demand. Improved computerized analytical methods and models will be adopted to provide rapid response and flexibility in considering the types of resources, and changes in costs, prices, uranium demands, and production constraints.

Technology Applications

The Technology Applications program element has been designed to (1) improve resource assessment methodology and thereby increase reliability of uranium resource estimates, and (2) improve exploration technology to make the Uranium Resource Assessment program more efficient and cost-effective and, as a spin-off, to assist industry's uranium exploration activities. In addition, efforts have been made to integrate approaches to uranium exploration and resource assessment by characterizing uranium occurrences and developing models of genesis. These efforts are of particular importance for assessment of world-class and intermediate- and low-grade resources.

Investigations designed to improve resource estimates and production capability analyses will continue. These investigations will include estimation processes, factors used in the potential resource assessment, subjective estimation processes, quantification of uncertainties, improvements in economics and supply-demand modeling, and the use of total costs and prices in resource and supply analysis and reporting. Technology improvements which are closest to the commercialization stage will be emphasized for transfer to industry.

Those activities which are in direct support of world-class and intermediate-grade investigations will continue. These include metallurgical and mining system investigations and technology integration efforts to develop enhanced systems and techniques for resource identification and evaluation.

International Activities

Support of Nuclear Energy Agency (NEA) and International Atomic Energy Agency (IAEA) activities in resource assessment, exploration R&D, and extraction technology will continue. The NEA/IAEA International Uranium Resource Evaluation Project (IUREP) aims to expand world uranium resources by study of 40 identified candidate countries where the possibility for the discovery of uranium resources is high but where there has been inadequate exploration effort. The current Orientation Phase agreement expires in mid-July 1981, but an extension is expected. The study of some 10 countries would then be likely in FY 1982.

DOE will continue to contribute to collaborative projects to improve uranium exploration, appraisal, and production technology. The IAEA/NEA Joint Group of Experts on Research and Development in Uranium Exploration Techniques and the Joint Working Party on Uranium Extraction have several such cooperative technology development topics. In addition, bilateral cooperative activities with selected countries, such as Mexico and Niger, are being negotiated.

PLATE 1

NATIONAL URANIUM RESOURCE EVALUATION POTENTIAL AREAS (10/1/80)